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Adaptation of eye-movements to simulated hemianopia in reading and visual exploration: Transfer or specificity?

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ABSTRACT

Reading and visual exploration impairments in unilateral homonymous hemianopia are well-established clinical phenomena. Spontaneous adaptation of eye-movements to the visual field defect leads to improved reading and visual exploration performance. Yet, it is still unclear whether oculomotor adaptation to visual field loss is task-specific or whether there is a transfer of adaptation-related improvements between reading and visual exploration. We therefore simulated unilateral homonymous hemianopia in healthy participants and explored the specificity with which oculomotor adaptation to this pure visual-sensory dysfunction during uninstructed reading or visual exploration practice leads to improvements in both abilities. Our findings demonstrate that there is no transfer of adaptation-related changes of eye-movements and performance improvements between reading and visual exploration. Efficient oculomotor adaptation to visual field loss is highly specific and task-dependent.

1. Introduction

Unilateral homonymous hemianopia (HH) is the most frequent visual disorder after brain damage (Zihl, 2000). It is commonly caused by posterior cerebral artery infarction affecting the postchiasmatic visual pathway. In HH, vision is lost in both monocular hemifields contralateral to the side of brain injury (Zhang, Kedar, Lynn, Newman, & Biousse, 2006a; Zihl, 2000). Homonymous visual field defects are chronic manifestations since sufficient spontaneous recovery of the visual field is seldom (Zhang, Kedar, Lynn, Newman, & Biousse, 2006b; Zihl & Kennard, 1996). The majority of patients show persistent and severe impairments of reading (i.e., hemianopic dyslexia) (Schuett, Heywood, Kentridge, & Zihl, 2008a) and visual exploration (Zihl, 2000).

The cardinal symptoms of hemianopic dyslexia are slowed reading, visual omission and guessing errors as well as a severely altered reading eye-movement pattern (e.g., Leff et al., 2000; McDonald, Spitzyna, Shillcock, Wise, & Leff, 2006; Spitzyna et al., 2007; Trauzettel-Klosinski & Brendler, 1998; Zihl, 1995a, 2000). The visual exploration impairment is characterised by considerably increased exploration times, target omissions as well as longer and unsystematic oculomotor scanning patterns (e.g., Mort & Kennard, 2003; Pambakian et al., 2000; Tant, Cornelissen, Kooijman, & Brouwer, 2002; Zihl, 1995b, 1999, 2000). These hemianopic reading and visual exploration impairments have been reported early in the literature and are now well-established clinical phenomena (for early clinical reports, see Mauthner, 1881; Pfeifer, 1919; Poppelreuter, 1917/1990; Wilbrand, 1907).

Spontaneous adaptation of eye-movements to visual field loss and consequent improvements in reading and visual exploration performance is an equally well-known phenomenon with a long history. Poppelreuter (1917/1990) was the first to report spontaneous oculomotor adaptation in hemianopic patients. Very soon after brain injury, some patients spontaneously adopt eye-movement strategies allowing them to efficiently compensate for their visual-sensory dysfunction. As a consequence, even patients with the most severe visual field defect can regain normal reading and visual exploration performance (Gassel & Williams, 1963; Mackensen, 1962; Meienberg, Zangemeister, Rosenberg, Hoyt, & Stark, 1981; Zangemeister, Oechsner, & Freska, 1995; Zangemeister & Utz, 2002; Zihl, 2000, 2003). Yet, it is still unclear whether efficient spontaneous oculomotor adaptation to visual field loss in reading and visual exploration is task-specific, or whether there is a transfer of adaptation-related improvements between reading and visual exploration. Consequently, our understanding of oculomotor adaptation processes in homonymous visual field loss and thus current rehabilitation practice remains imperfect.

We recently investigated whether and to what extent healthy participants spontaneously adapt to a simulated HH in reading and in visual exploration (Schuett, Kentridge, Zihl, & Heywood, 2009).

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We demonstrated that simulated HH induced the hemianopic reading and visual exploration impairments in healthy participants. Over time, however, all participants showed efficient spontaneous oculomotor adaptation to this pure visual-sensory defect which led to improvements in reading and visual exploration performance. These adaptation processes seemed to occur spontaneously and rapidly, even in the absence of any instruction aimed at improving participants' performance (see also Poppelreuter, 1917/1990). To investigate whether spontaneous oculomotor adaptation is task-specific, or whether there is a transfer of adaptation-related improvements between reading and visual exploration, we conducted a new study that compares the effects of uninstructed reading and visual exploration practice on reading and visual exploration performance with simulated HH in a cross-over design.

2. Methods

2.1. Participants

Twenty-four naïve, healthy participants (8 males, 16 females) participated in this study. Mean age was 19.1 years (S.D.: 1.0) and subjects had on average 12.5 years of education (S.D.: 0.7). All participants were native English speakers with normal or corrected-to-normal vision, had no reading disorders, visual disorders or any other neurological disease or psychiatric condition, and gave their informed consent in accordance with the Declaration of Helsinki and with local ethical committee approval.

2.2. Eye-movement recording and simulating HH

We recorded eye-movements using a pupil and dual Purkinje image video eye-tracker (HS-VET, Cambridge Research Systems). Viewing was binocular and the position of the right eye was sampled at a rate of 250 Hz. We used a sixteen-point grid for equipment calibration which was carried out before each recording session and repeated before each task and block of trials. The Eizo FlexScan F56 monitor (100 Hz, 17″, 800 × 600 pixels) used for stimulus presentation subtended 40° horizontally and 32° vertically. Participants' eye level was at the centre of the screen and viewing distance was 38 cm. Their head was fixed by a circular head holder that was firmly attached to a forehead- and chinrest. Ambient room illumination was 1 lx. For controlling stimulus presentation and eye-tracking we used a visual stimulus generator (Cambridge Research Systems) running custom software.

The procedure used to simulate left- and right-sided HH (LHH, RHH) in healthy participants was identical to our previous study, in which we demonstrated that our simulation technique successfully induces reading and visual exploration impairments matching those of hemianopic patients (Schuett et al., 2009). A gaze-contingent visual display completely blanked one side of the screen relative to the current eye position; to simulate LHH or RHH, the side to the left or right of current fixation assumed the colour of the background (see Fig. 1). Based on current eye position (acquired at 2.5 times frame rate), screen update occurred within a single frame (maximum lag: 10 ms). The complete screen area was blanked when saccadic eye shifts landed at positions outside the registration area. Visual field sparing of the simulated HH was 1°, i.e., 1° between foveal eye position and the left or right visual field boundary remained visible (∼3 letters in the reading task).

We validated the calibration and accuracy of the simulated visual field boundary before each task and block of trials by assessing the offset between actual and measured eye position using a nine-point grid. If the validation error was smaller than 1° on average and smaller than 0.5° at each point, we repeated the calibration and validation procedure. The accuracy of the simulated visual field boundary was continuously monitored on a control display; in cases of mismatch between actual and measured eye position, we also repeated calibration and validation. Trials with >20% loss of eye-movement data (resulting from lid closures or saccadic eye shifts to positions outside the registration area) were discarded from the analyses (2.3% of trials).

2.3. Assessment of reading performance and eye-movements

For assessing reading and eye-movements during silent text reading we used the same reading task as in our previous study which we demonstrated to be sensitive to adaptation-related changes during uninstructed reading practice with a simulated HH (Schuett et al., 2009). The reading task consisted of four text passages (taken from Oscar Wilde's (1931) "The selfish giant" (pp. 479–483)), each composed of 100 words arranged in eleven, left-aligned lines. Number of characters (including spaces) was similar across text passages (mean: 515.8, S.D.: 10.5). Letter size was 0.8°, letter width 0.3°; spacing between letters was 0.1° and 0.4° between words. About three characters subtended 1° of visual angle. Single lines were separated vertically by 2°. Luminance of the black letters was 0.2 cd/m^2, against a white background of 27 cd/m^2. Text passages were of low semantic and syntactic complexity level and consisted of short sentences. The difficulty level was well below the education level of our participants and none of them had read the text before. We previously demonstrated in a control sample of twenty-five healthy participants that there are no differences among the text passages in any of the parameters describing reading performance and eye-movements (Schuett et al., 2009); the maximal difference (within subjects) in reading time between any two of the four text passages was 2.1 s.

During the assessment of reading performance and eye-movements, we asked participants to read one of the four texts passages silently and only once, with the goal of understanding the text's content. No further instructions were given on how to proceed. For testing comprehension and to confirm that participants had read the text, they were also asked to reiterate its content after reading, which all participants did correctly. Eye-movement recording was started at the onset of text presentation and ended after the participant indicated completion of reading. Reading performance was defined as the time required to read one text passage (reading time). In addition, we analysed the following global temporal and spatial oculomotor parameters for each text: number and mean duration (ms) of fixations, percentage of fixation repetitions (i.e., fixations at previously fixated points), number and mean amplitude (°) of forward (i.e., rightward) saccades, mean amplitude of return-sweep saccades (i.e., the mean first amplitude of eye-movements from the end to the beginning of the next line (°)) and scanpath length (i.e., the sum of all saccadic amplitudes (°)).

2.4. Assessment of visual exploration performance and eye-movements

For assessing visual exploration and eye-movements, we also used the same task as in our previous study which we demonstrated to be sensitive to adaptation-related changes during uninstructed visual exploration practice with a simulated HH (Schuett et al., 2009). The task consisted of five irregular stimulus patterns, each composed of 19, 20 or 21 black dots (diameter: 1°) on a white background presented in randomized order. Dot luminance was 0.2 cd/m^2, against a white background of 27 cd/m^2. Dot patterns subtended 18.6° horizontally and 12.4° vertically; minimal spatial separation of any pair of adjacent dots was 6°. Each dot pattern was preceded by the presentation of a fixation spot (0.5°) in the centre of the screen which once fixated, initiated the trial. Participants were asked to silently count the presented dots as accurately and as quickly as possible, and to report the counted number. They were neither informed about the number of dots nor received feedback on their counting performance. Eye-movement recording started with the onset of the dot pattern and ended when the participant reported the number of dots.

Visual exploration performance was defined as exploration time (the time required to perform one trial) and number of errors (all errors committed were omission errors). In addition, we analysed the following global temporal and spatial oculomotor parameters for each trial (five trials in total): number and mean duration (ms) of fixations, mean saccadic amplitude (°) and scanpath length (i.e., the sum of all saccadic amplitudes (°)).

2.5. Reading and visual exploration practice

The reading and visual exploration practice sessions (RP, VP) were identical to those used in our previous study (Schuett et al., 2009). All participants performed one RP and one VP session. During RP, participants were asked to read ten consecutively presented text passages (actual time spent practicing reading: ∼15 min.). Text passages were taken from Michael Ende's (1974) "The grey gentlemen", which none of the participants had read before. Characteristics and presentation mode of the texts as well as instructions were identical to those used for the assessment of reading performance. All participants reiterated the content of each text correctly. During VP, patients were asked to perform 30 trials of the visual exploration task used for assessing visual exploration performance (actual time spent practicing visual exploration: ∼15 min.). Both practice sessions gave participants the opportunity to learn how to read and explore abstract patterns with a simulated HH without specific advice and instruction to improve performance.

2.6. Procedure

Participants were randomly allocated into two equal groups: Group A (n = 12) first performed the reading practice (RP), then the visual exploration practice (VP) session; Group B (n = 12) did the converse and first performed the VP, then the RP session in a cross-over design. Half of each group (n = 6) performed the two practice sessions with a RHH, the other half with a LHH. Reading and visual exploration performance and eye-movements were assessed before ($T1$) and after ($T2$) the first practice session, after the second practice session ($T3$), and then in a normal viewing condition (N), i.e., without any simulated HH (see Fig. 2). Both the sequence of assessment tasks (performing the reading or visual exploration task first) and that of texts (passages 1–4) used for reading assessment were counterbalanced across participants to eliminate order effects. There were no differences between Group A and B either for demographic variables or for reading and visual exploration performance and oculomotor measures before practice ($T1$) and in the normal viewing condition (N) (see Table 1).

In order to disentangle the effects of adaptation to simulated HH from performance changes due to mere practise effects, a new group of six participants (6 females; mean age: 19.3 (S.D.: 1.0); mean years of education: 12.2 years (S.D.: 0.4)) performed the same experimental protocol without any simulated HH (control condition).